Theor. Appl. Climatol. 81, 133–135 (2005)
DOI 10.1007/s00704-004-0112-1

Theoretical and Applied Climatology
Printed in Austria

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Is Granger causality analysis appropriate to investigate the relationship between atmospheric concentration of carbon dioxide and global surface air temperature?

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Received March 26, 2004; revised October 20, 2004; accepted November 28, 2004
Published online February 16, 2005

Summary

Many time series based studies use Granger causality analysis in order to investigate the connection between atmospheric carbon-dioxide concentrations and global mean temperature. This note re-examines the causal relationship between these variables and shows the inappropriateness of the Granger test to the problem under investigation.

1. Introduction

Several researchers have used the standard Granger causality analysis to investigate the causes of the historically observed rise in global temperatures. Young (1991) presents a vector autoregression model to analyze the causal relationship between atmospheric CO_2 concentrations and global sea surface temperatures. Kaufmann and Stern (1997) test whether southern hemisphere temperatures Granger cause northern hemisphere temperatures. A bivariate time series regression approach similar to the Kaufmann-Stern analysis is used by Smith et al. (2003). The analysis of Sun and Wang (1996) suggests that global carbon dioxide emission is Granger causal to global surface temperature, but past temperatures do not significantly improve the predictability of current CO_2. Tol and de Vos (1993 and 1998) find that the atmospheric concentration of carbon dioxide Granger causes the annual global mean surface air temperature. This note explores the causal relationship between atmospheric CO_2 concentrations and temperature goes beyond the standard Granger causality econometric techniques used in previous work. Granger causality tests are conducted, with a proper allowance for the non-stationarity of the data. In particular, the dynamic relationships between global surface temperature and global carbon dioxide concentration are examined using the methodology developed by Toda and Yamamoto (1995).

2. Empirical analysis

The variables used in the analysis are the following: (1) CO_2 concentration (C), (2) global surface temperature (TE), (3) southern hemispheric surface temperature (TE_s). The CO_2 atmospheric concentration annual data, expressed in parts per million, are from the Mauna Loa observatory since 1959, for the missing year 1964 we used a fitted datum (C.D. Keeling, T.P. Whorf, and the Carbon Dioxide Research Group Scripps Institution of Oceanography (SIO) University of California La Jolla, California USA). Prior to 1959 we used data from the Law Dome DE08, DE08-2 and DSS ice cores (D.M. Etheridge, L.P. Steele, R.L. Langenfelds, R.J. Francey, Division of Atmospheric Research, CSIRO, Aspendale, Victoria, Australia, J.-M. Barnola, Laboratoire of Glaciologie et Geophysique de l'Environnement, Saint Martin d'Heres-Cedex, France and V.I. Morgan Antarctic CRC and Australian Antarctic Division, Hobart, Tasmania, Australia). The global and hemispheric average surface temperatures are obtained from the Climate Research Unit at the University of East Anglia.

The mechanisms underlying the relationship between CO_2 concentrations and temperature are well understood. They have to do with the radiative trapping properties of CO_2. The physical climate system responds to changes in radiative forcing. Thus a model that relates temperature change to CO_2 atmospheric concentration change is misspecified. For calculate the radiative forcing (RC) due to CO_2 we have used the following simplified expression

$$RC = 5.35 \ln(C/C_0)$$

with $C_0 = 280$, where 280 is the assumed pre-1750 CO_2 atmospheric concentration. This formula, proposed in Myhre et al. (1998), is a revision of the formula adopted by the Intergovernmental Panel on Climate Change (IPCC) (IPCC-I, 1990, p. 56).[1]

What we need to know to apply the methodology of Toda and Yamamoto to investigate the causal relationships between radiative forcing due to CO_2 concentration and global surface temperature is the maximum order of integration d of the variables. Previous studies (cfr., Galbraith and Green, 1992; Seater, 1993; Stern and Kaufmann, 1999) indicate that the temperature series are trend stationary or $I(1)$, while the CO_2 concentration series is $I(1)$ or $I(2)$. Thus we conduct the causality tests using $d = 1$ and $d = 2$. We estimate a VAR model of the form:

$$v_t = a + bt + A_1 v_{t-1} + \cdots + A_{p+d} v_{t-(p+d)} + \varepsilon_t \qquad t = 1, \ldots, T.$$

where $v_t = (RC_t, TE_t)'$, a and b are two (2×1) vectors of coefficients, t is a deterministic time trend, A_i are (2×2) matrices of coefficients, ε_t is a white noise bi-dimensional. The maximum lag length p was chosen using the Schwarz model selection criteria (SBC).[2] Causality tests are conducted over the entire period 1860 to 2000 and for ten subperiods (the first subperiod is 1860–1900, the second is 1860–1910, etc.). The results of causality tests are summarized in Tables 1 and 2. An insignificant statistics means that there is no causality present, while a significant statistic indicates that the non-causality

Table 1. Results causality test from CO_2 to global temperature, $d = 1$

Period	Test statistic λ_W^*	p-value
1860–1900	4.4186	.352
1860–1910	3.2059	.361
1860–1920	2.6877	.442
1860–1930	4.8839	.180
1860–1940	2.8913	.409
1860–1950	1.5591	.669
1860–1960	2.5278	.470
1860–1970	1.0513	.591
1860–1980	3.3462	.188
1860–1990	5.2276	.073
1860–2000	5.4489	.066

Note. * Significant at the 5% level
** Significant at the 1% level

Table 2. Results causality test from CO_2 to global temperature, $d = 2$

Period	Test statistic λ_W^*	p-value
1860–1900	6.1624	.291
1860–1910	6.2255	.183
1860–1920	6.4803	.090
1860–1930	8.7474**	.033
1860–1940	5.3518	.148
1860–1950	4.7206	.193
1860–1960	5.4619	.141
1860–1970	.0501	.997
1860–1980	2.3607	.307
1860–1990	4.6697	.097
1860–2000	5.8000	.055

Note. * Significant at the 5% level
** Significant at the 1% level

[1] The form is equal to IPCC-I (1990) but with new value of the constant.

[2] We have computed SBC for selecting the order of the VAR(p), for $p = 1, 2, \ldots, 10$. It is important that the maximum order chosen, 10, for the VAR is high enough, so that high-order VAR specifications are given a reasonable chance of getting selected, if they happen to be appropriate.

hypothesis is rejected. The overall results show that there is no detectable causality from CO_2 to temperature. For $d = 1$ we cannot reject the null hypothesis of non-causality for any subperiod. A weak evidence of CO_2 to temperature causal order appears only over the entire period. For $d = 2$ we can reject the null hypothesis of non-causality only over the 1860–1930 period. Again, there is a weak evidence of CO_2 to temperature causal order over the entire period 1860–2000.

3. Conclusions

In recent years, the Granger causality analysis has been extensively used to test the hypothesis that the greenhouse gases are responsible for part of the global warming experienced to date. We re-examined the causal link from global carbon dioxide concentration to global surface temperature, using the methodology developed in Toda and Yamamoto (1995). Our results show that there is no detectable Granger causality from CO_2 to temperature. In other terms, past observations of CO_2 do not significantly improve the predictability of current temperature. Since the mechanisms underlying the relationship between CO_2 concentrations and temperature are well understood, our (negative) result, shows the inappropriateness of the Granger test to the question under investigation. The year-to-year signal of greenhouse gas forcing should be about .005 °C. Compared to year-to-year variability of the global mean temperature of about .25 °C one may expect that the quality of a one year forecast would not be significantly enhanced if anthropogenic greenhouse gases were taken in account, especially since it has to compete with a pre-given trend and an autoregressive part. Finally, we observe that the causation from radiative forcing to temperature is slow, thus others time series techniques as Koyck and Almon distributed lags could be more appropriate.

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